SILVER LAKE

LAKE LAY MONITORING PROGRAM

1983

Freshwater Biology Group (FBG)

University of New Hampshire

Durham

by

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PREFACE

A non-technical, comprehensive summary can be found at the end of the introductory section. The summary is intended to provide a quick reference to the main findings of the study. A list of all data collected by the lay monitors at Silver Lake is included in Appendix A. The data will be maintained on the computer files of the Freshwater Biology Group, and are available for use by both the Silver Lake Association and the FBG. Appendix B is intended as a brief primer on limnological concepts. A glossary is included as a reference to limnological terms used in the text.

The Lake Lay Monitoring Program (LLMP) has been increasing its activities during the past two years, and presently includes 16 associations and more than 25 lakes. A map of the state of New Hampshire is included at the end of the introductory section, with locations of the lakes in the LLMP.

ACKNOWLEDGEMENTS

1983 is the first year Silver Lake has been been a participant in the Lake Lay Monitoring Program. Mostly through the efforts of Dr. Lawrence Slanetz, the program has developed strongly on Silver Lake. Lay monitors on Silver Lake included:

Site 1 -- L. Slanetz, R. Benford, W. Jones

Site 2 -- L. Slanetz, R. Benford, W. Jones

Site 3 -- Percy Hill, B. Beck, Kennett, L. Slanetz.

Site 4 -- Percy Hill, B. Beck, and Kennett.

Site 5 -- Percy Hill, B. Beck, and Kennett.

We congratulate the lay monitors on the quality of their work, and anticipate that they will continue with the program next year. We also express our appreciation to Dr. Slanetz and all the other members of the Silver Lake Association for their time and effort. Also, we thank everyone who provided boats for our visiting team.

Members of our Freshwater Biology Group field team included Kim Babbitt, Dan Hayes, Wayne Boisselle, Tom Balf, and Mike Martin. Dan was team leader, and was responsible for coordinating all data analysis and interpretation. He and Tom were the zooplankton experts. Mike was the phytoplankton expert. Kim and Wayne specialized in

phosphorus and chlorophyll _a_ analysis. All members of the team helped in data organization and filing. Also, all team members participated in field trips throughout the summer.

This report has been produced in large part with data management and word processing programs on the UNH DEC-10 computer. Graphics were produced with program UPLOT, written by Professor Baker, and the CALCOMP drum plotter available on the DEC-10 system. The Office of Computer Services kindly provided computer time and data storage space for the Lake Lay Monitoring Program.

INTRODUCTION

This report presents the finding of the 1983 summer study of Silver Lake. The study was conducted jointly by the Freshwater Biology Group (FBG), University of New Hampshire, and by the Silver Lake Association, as part of the Lake Lay Monitoring Program (LLMP). The LLMP is a long-term water quality monitoring program that relies heavily on the efforts of lay persons. In Durham, the LLMP is conducted by Dr. Alan L. Baker (Associate Professor of Botany) and Dr. James F. Haney (Associate Professor of Zoology), who direct a team of trained graduate and undergraduate students. Space and research facilities were provide by the Departments of Botany and Zoology at the University of New Hampshire. Secretarial services were provided by the Department of Zoology.

The LLMP is a cooperative effort between the FBG and cooperating lake associations, conservation commissions, and municipalities. Funding for the program is derived solely by contributions from the participating groups. During 1983, the participating groups included: Walker Pond Protection Association, Town of Hudson, Town of Salem, Town of Merrimack, Town of Amherst, Lake Chocorua Conservation Federation, Winona Lake Association, Lake Winnipesaukee Association, Squam Lake Association, Merrymeeting Lake Association, Pleasant Lake Association, Silver Lake Association, Bow Lake Association, and Kanasatka Lake

Association.

The LLMP has two major goals: first, to carry out scientific investigations on participating lakes in order to provide a data-base on lake biology, physics, and chemistry; and second, to educate people about lakes and their management. A broad data-base on lakes is necessary for their proper management, but is often lacking. Through the efforts of lay monitors and FBG members, such a data base can be provided. This commitment is long-term due to the long period of time it may require a lake to exhibit signs of disturbance. Continued monitoring from year to year is essential for the early detection of changes in lake conditions.

Education is also an important goal of the LLMP. Through education, people's awareness of lakes and human activities that may influence lakes is heightened.

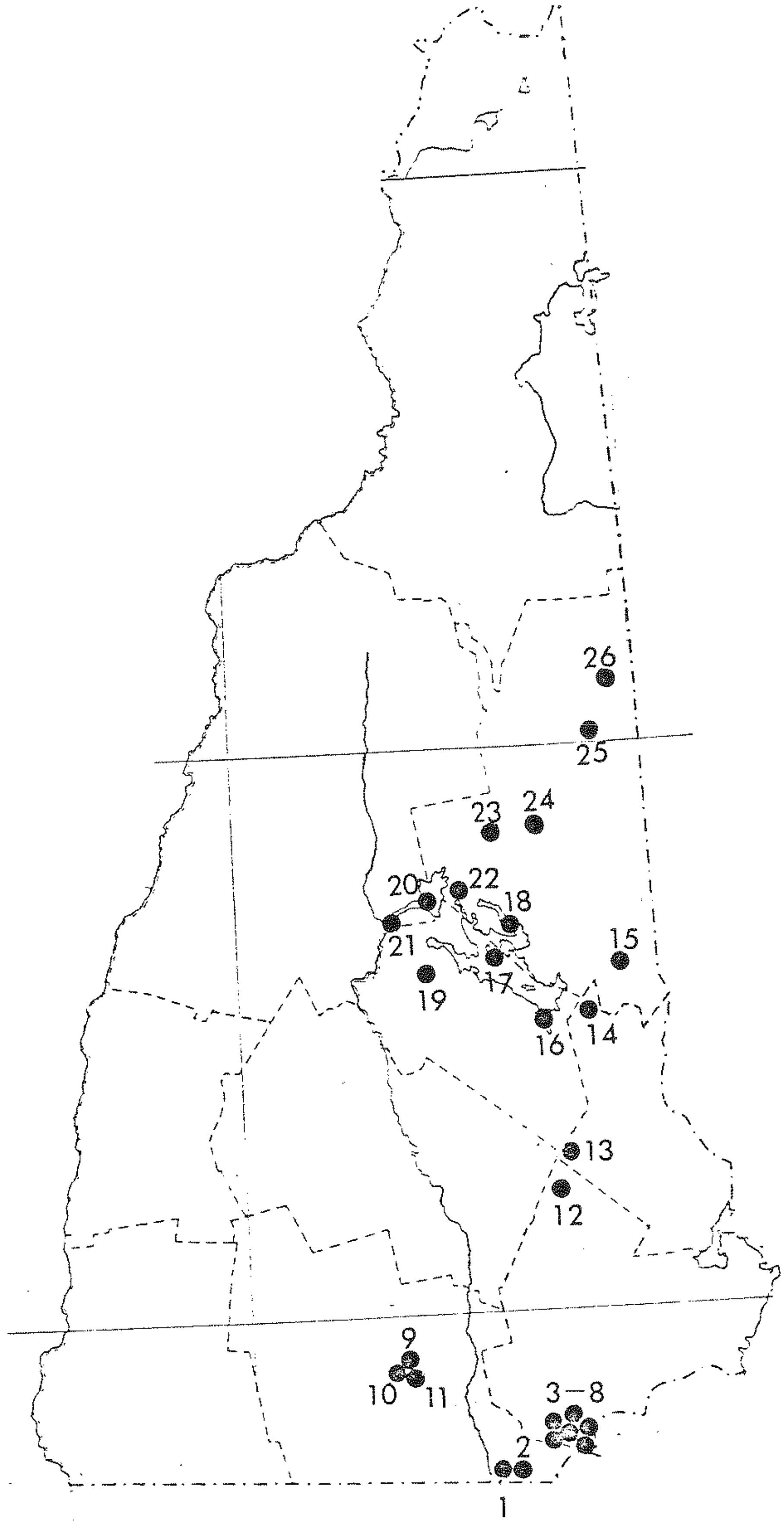

Figure 1.

Key to Figure 1: Lakes previously or presently in the LLMP of New Hampshire.

Map Location	Lake Name	Number of FBG Observations	Number of Lay Observations
1	Ottarnic Pond	11	37
2	Robinson Pond	10	79
3	Arlington Mill Resevoir	20	78
4	Canobie Lake	15	29
5	Millville Lake	10	84
6	Shadow Lake	9	17
7	World's End Pond	0	12
8	Captain's Pond	0	7
9	Naticook Pond	2	9
10	Horseshoe Pond	0	14
11	Baboosic Lake	11	48
12	Pleasant Lake	6	72
13	Bow Lake	2	0
14	Merrymeeting Lake	12	58
15	Lovell Lake	2	0
	Lake Winnipesaukee		
16	Alton Bay	2	85
17	Long Island	0	38
18	Moultonborough Bay	26	172
19	Winona Lake	4	4
20	Squam Lake	18	358
21	Little Squam Lake	14	76
22	Kanasatka Lake	0	3
23	Bearcamp Pond	7	86
24	Silver Lake	2	50
25	Lake Chocorua	9	16
26	Conway Lake	5	28

Brief Non-technical Summary

1) The water quality in Silver Lake is good based on the high water transparency (deep Secchi disk depth), and small amount of algae (low chlorophyll a concentration).

2) The trend in water quality in Silver Lake cannot be determined from a single year's data. Saying that the water quality is good this year does not mean that the water quality is improving or degrading.

4) The effects of acid rain on Silver Lake are not yet critical. There is an apparent decrease in the alkalinity since the 1930's, however. This means that the lake is losing its natural resistance to the effects of acid rain. If the trend is continued, the problem will become critical in the future.

5) The data collected by lay monitors and the Freshwater Biology Group represents a good beginning on a long-term data base for Silver Lake. Continued monitoring will serve to add to this data base, and provide a valuable record of water quality from year to year.

Comments and Reccommendations for Silver Lake 1983

1) The consistency of data collection from the lay monitors has been excellent throughout the 1983 season. The data base obtained during 1983 will certainly serve as a good starting point for future monitoring. With such a data base, comparisons can be made from year to year as a constant check on water quality.

2) To better monitor the effects of acid rain, the Silver Lake Association should attempt to obtain samples for pH and/or alkalinity. Samples obtained around the time of spring thaw when acid shock (low pH) may occur would be especially valuable.

3) As the phosphorus concentration was unexpectedly high, we suggest that lay monitors collect phosphorus samples during 1984. This will serve to increase the seasonal and spatial coverage of monitoring on Silver Lake.

Executive Summary for Silver Lake 1983

1) Silver Lake is oligotrophic based on Secchi disk depth, chlorophyll *a* concentration, algae, and zooplankton. The chlorophyll *a* concentration was low, with a summer average for lay data of 0.8 mg/cubic meter. The average Secchi disk depth was 6.7 meters (about 22 feet). Total phosphorus was moderate, with an average of 15.4 micrograms/liter. This phosphorus concentration is higher than expected, based on chlorophyll *a* concentrations. The density of phytoplankton was low (479-585 cells per milliter). The species composition was indicative of an oligotrophic system, and was composed primarily of diatoms. The density of herbivorous crustacean zooplankton was low to moderate with 4-10 animals per liter. The dominant group was calanoid copepods, followed by *Daphnia*. Large numbers of herbivorous rotifers were noted while counting crustaceans from site 2.

2) The surface pH of Silver Lake was rather low, in the range 6.0 to 6.2. Alkalinity was also low, with an average of only 5.7 mg/liter in the surface waters. The low levels of alkalinity present in Silver Lake mean that the lake has a low capacity to resist the effects of acid precipitation.

3) Dissolved oxygen concentration in the hypolimnion was very high, and showed little sign of depletion even during July. This high oxygen concentration is indicative of oligotrophic conditions.

4) The specific conductivity of the lakewater is low (34.1 microhms per cm.), as is the concentration of chloride ions (2.4 parts per million). This indicates that input of salts through road salting and/or raw sewage are minor.

METHODS OF LAY MONITORS

Lay monitors collected data on three parameters: thermal stratification, water clarity, and chlorophyll a concentration. Data were collected at weekly intervals whenever possible.

Thermal profiles were obtained by collecting lakewater samples at several depths with a modified Meyer bottle (Lind, 1979). Samples were obtained by lowering the empty but weighted bottle and sampling (by pulling out the stopper) at 1-meter intervals. The temperature of the samples was measured with Taylor pocket thermometers, and recorded in degrees Celsius.

Water clarity was measured while lowering an 8-inch (20 cm) Secchi disk and holding a view-scope just below the surface to eliminate the effects of surface reflection and wave-action. When the Secchi Disk disappeared the depth mark on the plastic suspension line was noted. The disk was raised until it just came into sight, and again the depth on the line was noted. The process was repeated two to three times, and an average between the two marks on the line (the point of disappearance and the point of re-appearance) was considered to be the Secchi Disk Depth (SDD), measured to the nearest one-tenth meter (0.1 meter) -- as for example, 5.2 meters. Readings were generally taken between 9 a.m.

and 3 p.m., the period of maximum light penetration.

Chlorophyll a concentration was used as an estimator of algal biomass. A weighted tube 33 feet (10 meters) in length was used to collect an integrated water sample from the 'upper-lake' (epilimnion). The weighted end of the tube was slowly lowered to the interface of the epilimnion and the 'middle-lake' (metalimnion). The end of the tube was then bent double to shut off flow of air and water, and the weighted end of the tube (presently at the base of the epilimnion) was pulled up to the surface with a plastic line attached to it. The water in the tube (epilimnetic lakewater sample) was poured into a plastic bottle by placing the weighted end of the tube into the neck of the bottle and, while keeping the bent-off end above the weighted end, unbending the upper end (allowing the sample to discharge into the bottle).

Water samples were filtered through a membrane filter with a porosity of 0.45 microns. The damp filters containing chlorophyll-bearing algae were air dried for at least 15 minutes to prevent decomposition. Filtration and drying were done in the shade to minimize destruction (by bleaching) of chlorophyll. The dried filters were then sent to UNH for analysis. [In Durham, members of the Freshwater Biology Group extracted chlorophyll in 90% acetone saturated with magnesium carbonate, and read the absorbance of the sample at standard wavelengths (663 and 750 nanometers). If sufficient pigment was present, the sample was acidified and reread to enable estimation of the percentage of active chlorophyll relative to the sum of the pigment plus all of its breakdown products that were present.]

METHODS OF FRESHWATER BIOLOGY GROUP (FBG) TEAM

The same as well as additional parameters were investigated by the FBG research team. The additional factors were primarily measurements of sunlight penetration into the lakewater, and water chemistry. The latter included dissolved oxygen, 'free' (unbound) carbon dioxide, pH, specific conductivity, chloride ion, and total phosphorus. In addition, the microscopic plants (phytoplanktonic algae) and animals (zooplanktonic invertebrates) were identified. Relative or absolute counts were made.

Dissolved oxygen and temperature were measured with a Yellow Springs Instruments Model 54A Oxygen/Temperature meter with a submersible probe. Readings were taken at 1-meter intervals throughout the 'upper-lake' (epilimnion) and 'lower-lake' (hypolimnion), and at half-meter intervals through the 'middle-lake' (metalimnion).

Sun- and skylight penetration into the lakewater was measured at 1-meter intervals with a Whitney submersible photometer model LMA-8A, and the relative light intensity was recorded. Measurements were taken on the sunny side of the boat.

Dissolved water colcr was measured by reading the absorbance of filtered lakewater (0.45 micron) at 440 and 493 nanometers, in a Bausch and Lcmb Spectronic 710 with a path length of 15 cm.

Water chemistry (alkalinity, free carbon dioxide, pH, and specific conductivity) samples were collected with a 3-liter Van Dorn bottle. Samples to be analyzed for alkalinity, free carbon dioxide, specific conductivity, and pH were stored on ice in 250 ml pclyethylene bottles.

Alkalinity, free carbon dioxide and pH were determined in the field, within 1 to 2 hours of sampling.

Alkalinity was determined titrimetrically with 0.002 N sulfuric acid to a final pH of 4.5, with a ccmbination solution of the two dyes bromocresol green and methyl red as the end-point indicator (E.P.A.,1979). Alkalinity is expressed as equivalents of calcium carbonate.

'Free' (unbound) carbon dioxide concentration was determined by titrating the fresh lakewater samples with 0.0027 N NaOH to a final pH of 8.3, and with the dye phenolphthalein as the end-point indicator.

pH was measured with a pH meter (Corning Model 10) equipped with a combination probe (Orion Co.).

Specific conductivity was measured with a Barnstead Conductivity Bridge Model PM-70CB equipped with model B-10 probe (cell constant = 1.0). Correction for sample temperature was made with a standard curve.

Chloride ion concentration was measured with a pH meter (Corning Model 10) equipped with a chloride electrode (Orion model 94-17B) and a double junction reference electrode (Orion Model 90-02). Standard curves were prepared every 2 hours during laboratory analysis.

Samples to be analyzed for total phosphorus, phytoplankton, and chlorophyll a were collected with a vertical 'tube' sampler. Chlorophyll a samples were filtered, dried and analysed in the same manner as those collected by lay monitors.

Total phosphorus samples were stored in acid-washed 250 ml polyethylene bottles, and were fixed within 1 to 2 hours with 1.0 ml concentrated sulfuric acid. In their Durham laboratory, the FBG members digested the total-phosphorus by adding ammonium persulfate and autoclaving the samples for at least 45 minutes. Finally, the phosphorus content of the samples was analyzed with the single-reagent method that included a fresh solution of ascorbic acid and potassium antimony tartrate (E.P.A., 1979). Absorbance of the blue phosphorus complex was measured spectrophotometrically at 650 nm.

Phytoplankton samples were fixed with iodine (Lugol's Solution) in the field, within 1 to 2 hours after collection. Phytoplankton were counted with a Unitron 'inverted' microscope after settling the samples for 24 hours in counting chambers. At least 200 individual algal 'units' were counted with a modified scan technique (Baker 1973).

Zooplankton density was estimated in samples collected by towing up a plankton net (30 cm diameter, 150 micron porosity) through the oxygenated (>0.5 ppm) portion of the lake. Samples were fixed after collection with a 4% formalin-sucrose solution (Haney and Hall, 1973), and subsampled with a 1-ml Hensen-Stemple pipet. Sufficient subsamples were taken to insure that at least 100 microcrustaceans were counted.

RESULTS AND DISCUSSION OF LAY MONITOR DATA

Lay monitor research was conducted separately from Freshwater Biology Group (FBG) research, thus the results are presented separately. Five sampling sites were established on Silver Lake (Fig 2). The lay monitor data for summer 1983 are presented in Appendix A.

Lay monitors collected information on three parameters: water transparency (Secchi disk depth), productivity (chlorophyll a), and thermal stratification (temperature profile). Information on thermal stratification is used mostly to determine the depth of the chlorophyll a sample. The lake was stratified during the entire sampling period (late July-August).

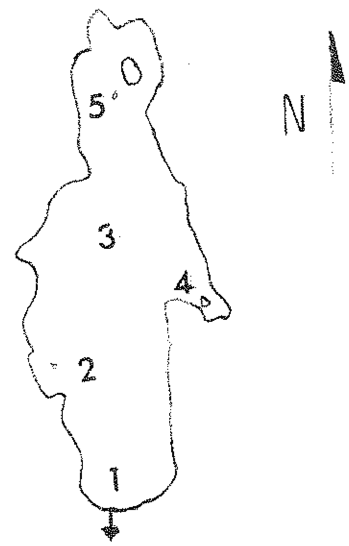

Figure 1. Silver Lake, Town of Madison, New Hampshire.

Secchi Disk Depth (transparency)

Site 3 had the deepest average water transparency (7.2 meters), although this difference is probably not significantly different from the transparency at site 2 (7.0 meters). The average Secchi disk depth at site 1 was 6.7

meters, and the readings were usually shallower than at Sites 2 and 3 (Fig. 3). Site 5 had an average transparency of 6.3 meters, consistently shallower than the transparency at sites 1, 2, and 3. Site 4 was too shallow for Secchi disk readings (5.5-5.6 meters). Seasonally the transparency was shallowest during late July and August and increased during September.

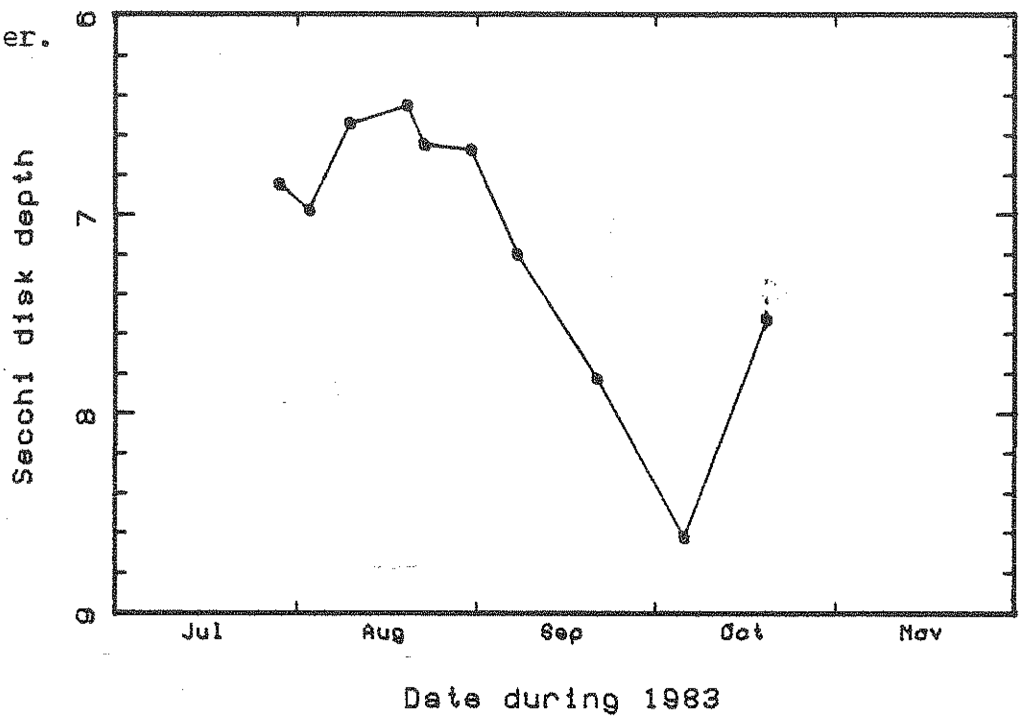

Figure 3. Seasonal variation of Secchi disk depth (meters).

Chlorophyll a

The average summer chlorophyll a concentration was similar at all sites, as was the seasonal pattern (Fig. 4). The most noteworthy element in the seasonal pattern is the marked decrease in chlorophyll concentration in early September. As a result of the decrease, the average chlorophyll concentration for the season is greatly influenced by the time frame selected. For example, the concentrations were in the range 0.76-0.87 milligrams per cubic meter at stations 1 and 5 respectively, when all samples are included in the time frame of late July through late October. In contrast, the values decrease to 0.68 and 0.75 respectively, if only July and August are included. We point this out because most lake studies include only the summer months June through August. Future plans for monitoring Silver Lake should include a consideration of the time-frame affects on average chlorophyll values. t.p;The reason for the significant decrease in chlorophyll in early September is not known, as we have no phytoplankton counts for that time period. This would be useful to do in future studies. In any case, even the highest concentrations of chlorophyll are low relative to many lakes in the LLMP. Thus it is important to continue monitoring to be certain that the levels remain low.

A decrease in chlorophyll a was observed at four of the five

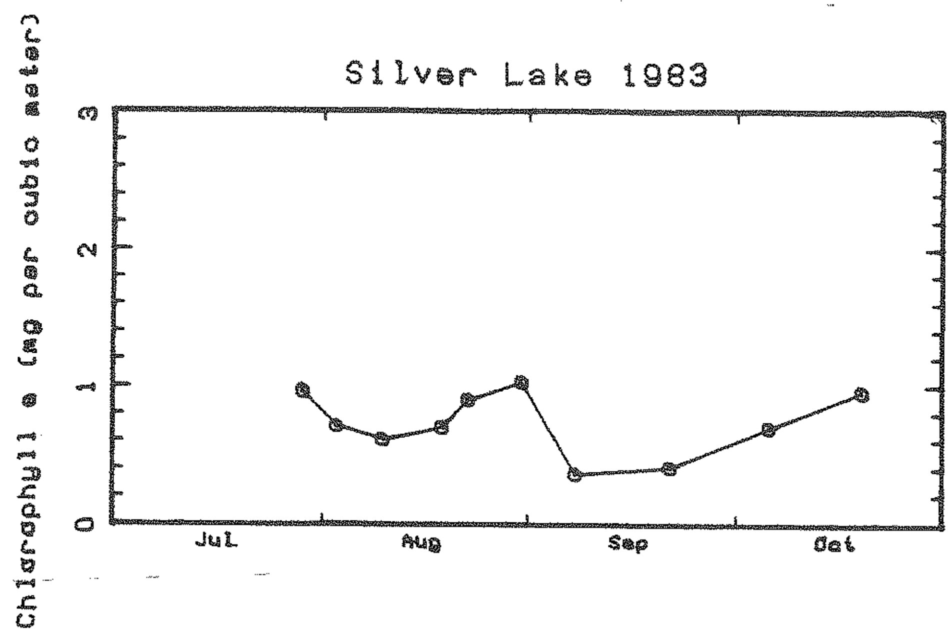

Figure 4. Seasonal variation of chlorophyll a.

Discussion

Lakewater in Silver Lake is relatively transparent compared to cther lakes in the LLMP. Based on Secchi disk depth and chlorophyll a concentration, Silver Lake is oligotrophic (Fig. 5, 6).

Differences in Secchi disk depth between sites are apparently not due to differences in chlcrcphyll a. Dissolved color and non-chlorophyllous particulates were not measured, but are protably the source of variaticn. Sites 2 and 3 were the deepest sites, and the furthest from any major inlets, which may explain in part their greater lakewater transparency. Because this is the first full year of lay mcnitoring on Silver Lake, no comparisons with previous lay data can be made. Data from other sources are sparse, and represent points in time rather than data from an entire season. On August 3, 1977, the New Hampshire Water Supply and Pollution Control Commission measured a Secchi disk depth of 7.5 meters, and a chlorophyll a concentration of 3.4 mg/l. The New Hampshire Fish and Game Department surveyed Silver Lake on July 19, 1937 and on June 29, 1950 when they measured Secchi disk depths of 6.7 and 5.5 meters respectively. These measurements provide little information on changes in trophic state of Silver Lake over the past 40 years. These data do, however, emphasize the value of having lay monitors test the lake over the entire season.

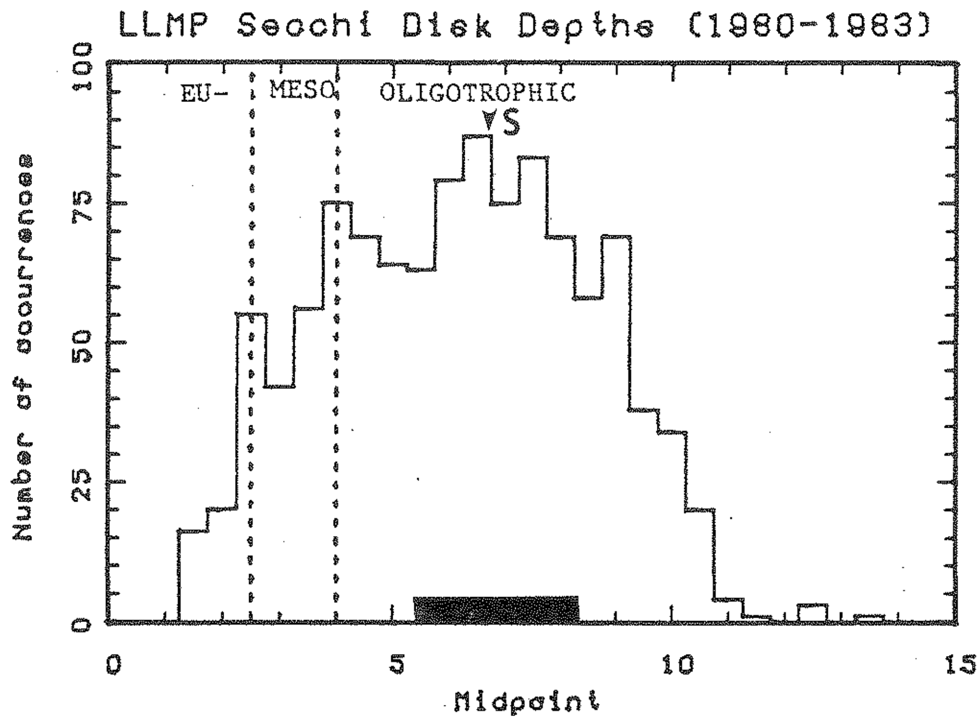

Figure 5. Frequency distribution of transparency (Secchi Disk depth in meters). Arrow indicates mean and bar indicates range of values from Silver Lake.

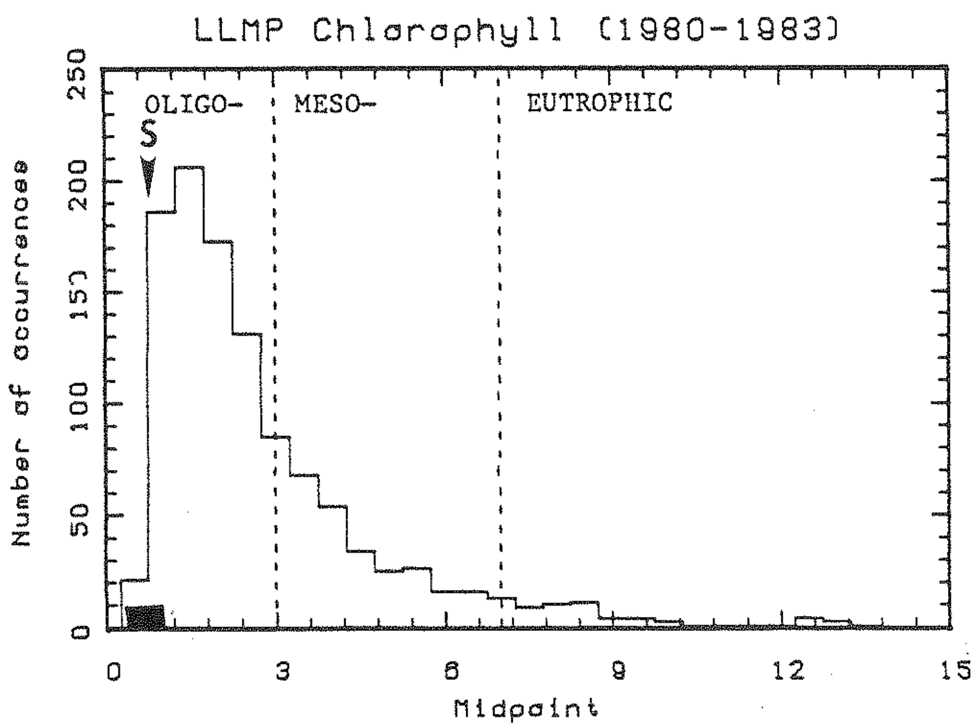

Figure 6. Frequency distribution of chlorophyll a (milligrams per cubic liter)

(milligrams per cubic meter) of all values in the LLMP. Arrow indicates mean and bar indicates range of values from Silver Lake.

RESULTS AND DISCUSSION OF FRESHWATER BIOLOGY GROUP DATA

Temperature and Dissolved Oxygen

Silver Lake was thermally stratified at both test sites on July 14, 1983. The epilimnion extended down to 4-4.5 meters, and the thermocline (metalimnion) extended from this point down to approximately 9.5 meters (Fig. 7). At both sites, the hypolimnetic temperature was in the range 7-9 degrees Celsius. Also, at both sites, the hypolimnetic oxygen concentration was above 9 parts per million. These conditions are very well suited for cold-water fish such as lake trout and land-locked salmon. The limited oxygen depletion indicates low productivity in Silver Lake.

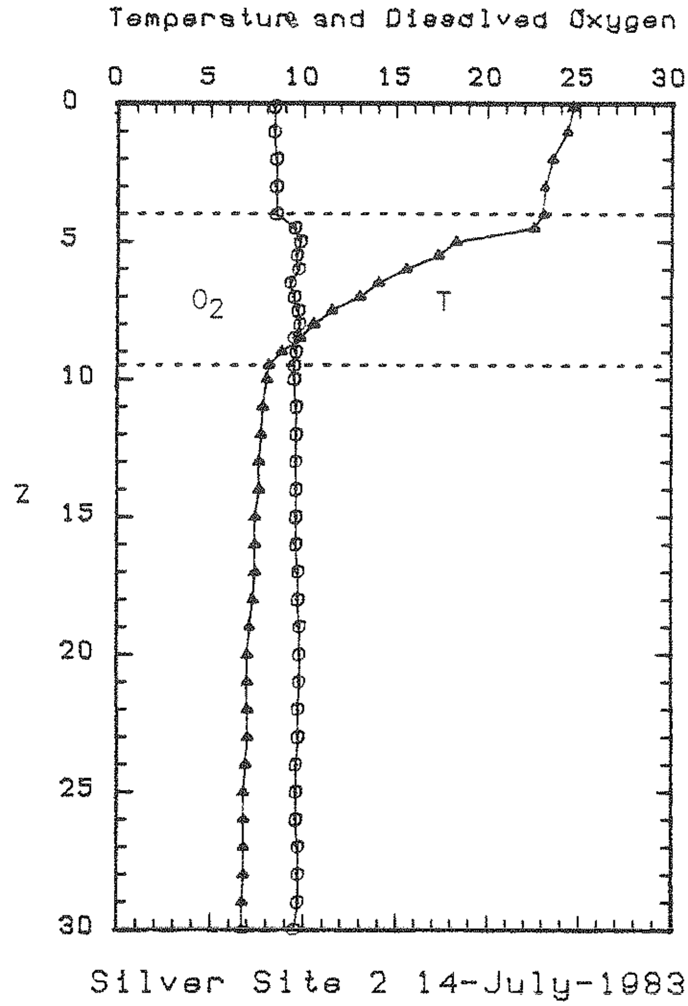

Figure 7. Profiles of temperature (Celsius) and oxygen (milligrams per liter).

<u>Water Clarity and Dissolved Color</u>

Lay monitors and FBG team members obtained similar Secchi disk depths on July 14, indicating that lay monitors are correctly obtaining their measurements.

Sunlight is quickly extinguished in lakewater due to absorbance by suspended particles and dissolved coloring material, and by scattering by these substances. A value describing the attenuation of light in lakewater is 'k', the extinction coefficient of diffuse downwelling light. In Silver Lake, k was in the range 0.448 to 0.497, and averaged 0.473. Relative to other lakes in the LLMP, this is a low value (Fig. 8), and corresponds to the deep Secchi disk depth in Silver Lake.

Dissolved water color, primarily due to humic acids, averaged 0.027 per 5 centimeters (absorbance at 440 nanometers) on July 14. Relative to other lakes in the LLMP, this is a relatively low value (that is, the water when filtered is relatively clear or 'free' from color (Fig. 9). The result of having low color is to allow light to penetrate deeper into the water column (higher transparency).

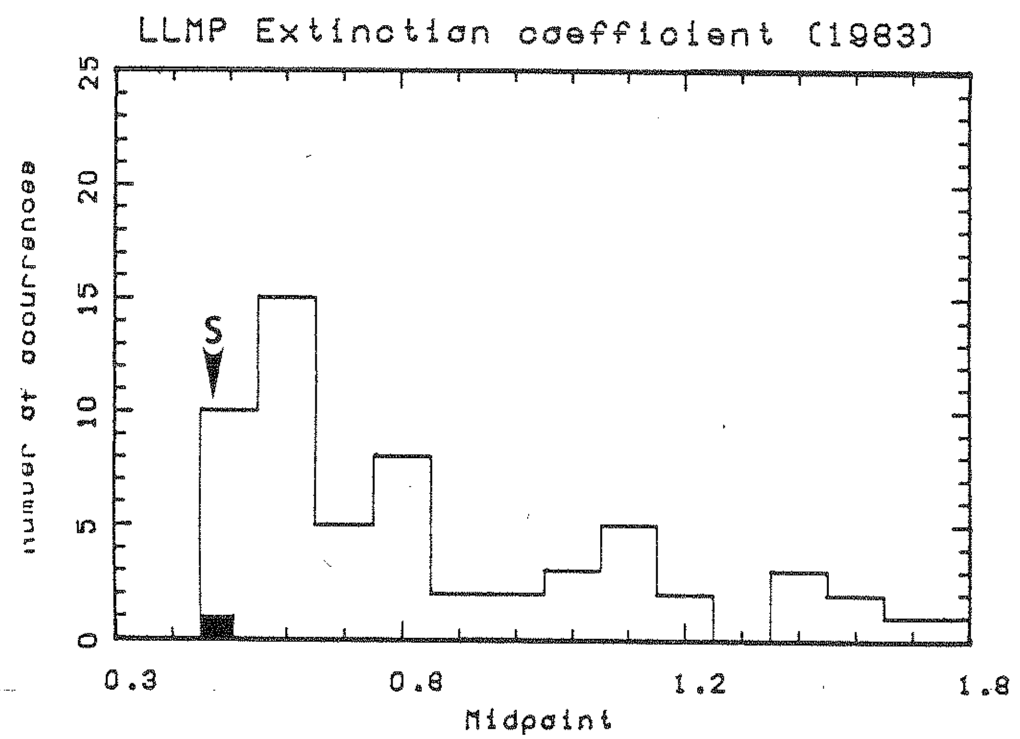

Figure 8. Frequency distribution of extinction coefficient, of lakes in the LLMP, showing mean of Silver Lake.

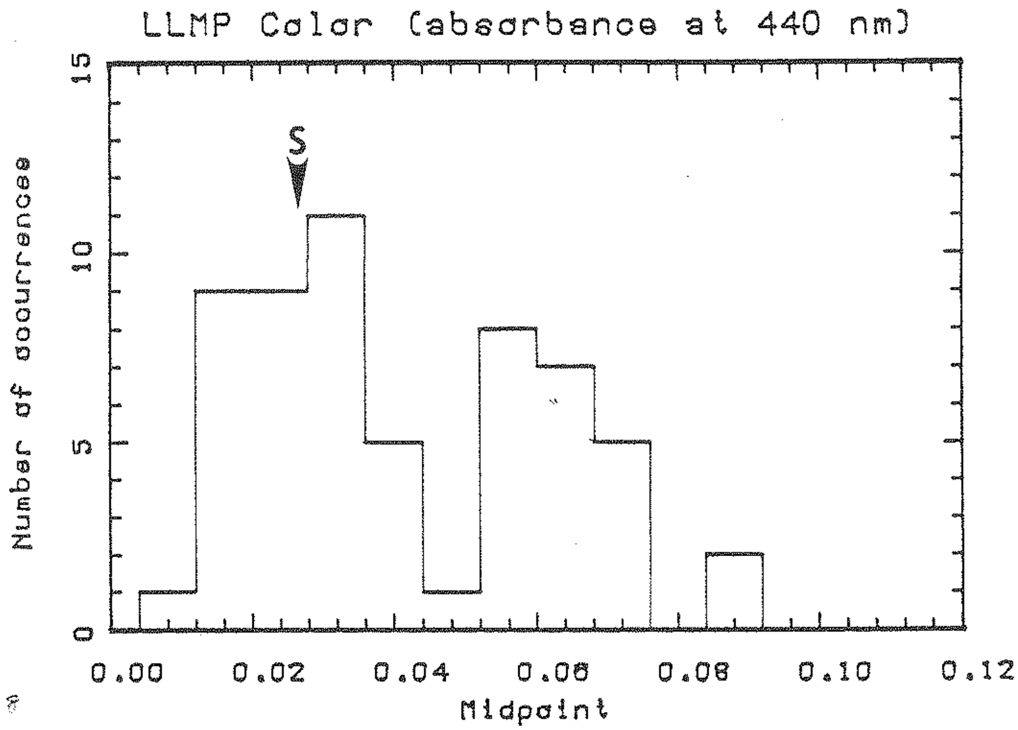

Figure 9. Frequency distribution of dissolved color of lakes in the LLMP, showing mean of Silver Lake.

Chlorophyll *a*

Chlorophyll *a* concentrations measured by the FBG were similar to those measured by the lay monitors. Concentrations were in the range 0.6 to 0.7 milligrams per cubic meter.

Total Phosphorus

Total phosphorus is usually the nutrient limiting algal growth in freshwater systems. Its concentration can be used to indicate the potential for algal growth. Concentrations were moderate at both sites, in the range 14.1-16.6 micrograms per liter (Fig. 10). These values are higher than expected based on chlorophyll *a* concentrations. Often, a high flushing rate will cause a lower chlorophyll a concentration than expected, but this does not appear to be the case, as Silver Lake has a flushing rate of 0.6 per year. Another possibility is that acid precipitation may be stressing the algal community, thus lowering its growth rate relative to the available phosphorus. More data is needed before any solid conclusions can be drawn, which suggests the possibility of having lay monitors collect phosphorus samples during 1984 in order to increase the seasonal and spatial coverage of the lake.

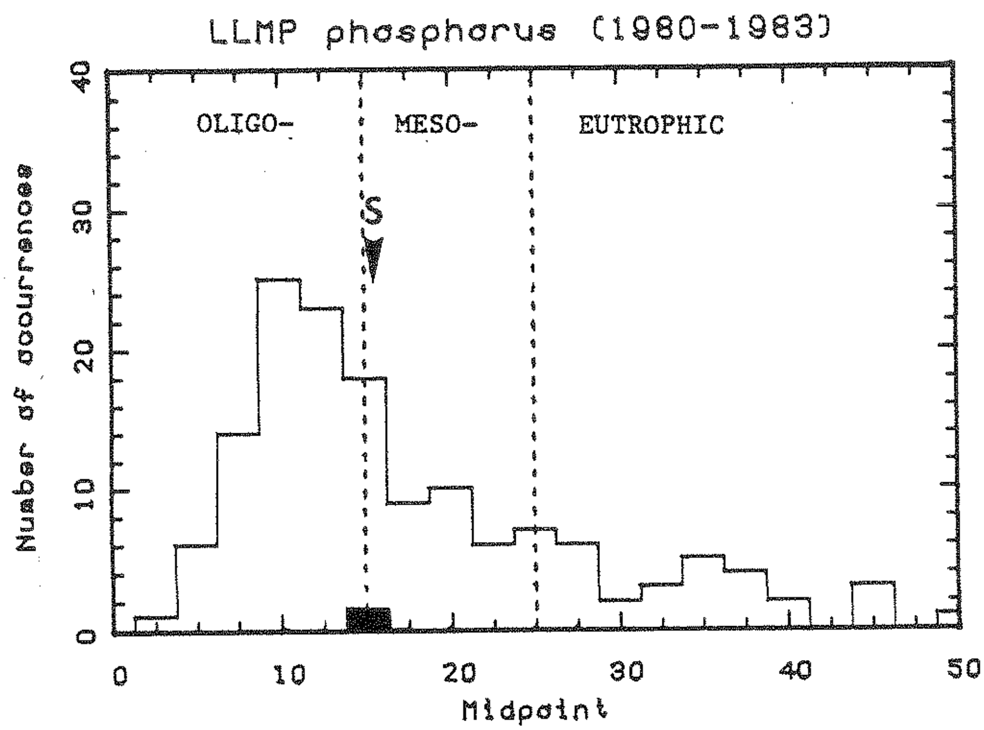

Figure 10. Frequency distribution of all phosphorus values in the LLMP (micrograms per liter). Mean phosphorus value in 1983 at Silver Lake is indicated by the position of the arrow.

Alkalinity, pH, and Free Carbon Dioxide

The vertical pattern of pH, alkalinity, and free carbon dioxide found at Site 1 on July 14 is typical of the lake (Fig. 11).

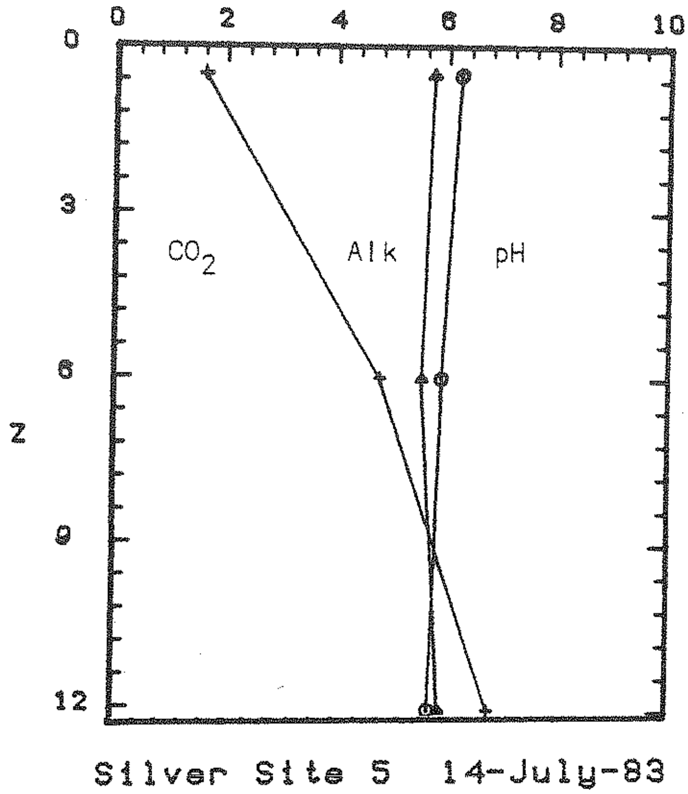

Figure 11. Profile of alkalinity (milligrams per liter), pH and free carbon dioxide (milligrams per liter).

The pH values of surface water in Silver Lake were moderate, in the range 6.0-6.2. Alkalinity, however, was low, with an average of 5.7 milligrams calcium carbonate per liter. The low alkalinity makes Silver Lake sensitive to the effects of acid precipitation. Data from historical sources is important as it indicates that Silver Lake has lost some alkalinity over the past 30 years. The alkalinity measured by the New Hampshire Fish and Game Department during 1937 and 1950 was 8 milligrams calcium carbonate per liter on both occasions.

Dr. Robert Newton of Smith College also has provided us with additional alkalinity information. On August 16, 1983, he measured an alkalinity of 3.5 mg per liter at site 1, and 3.2 mg per liter at site 2. Although his method is slightly different than the FBG method, it emphasizes the point that Silver Lake's alkalinity is very low, and should be watched closely during the future.

Free carbon dioxide accumulated in the thermocline and hypolimnion of Silver Lake. This lowers the pH of these layers of lakewater (Fig 10). The amount of free carbon dioxide in the deep waters indicates low productivity in Silver Lake.

<u>Specific Conductivity and Chloride Ion Concentration</u>

Silver Lake has one of the lowest salt concentrations among the lakes in the LLMP based on specific conductivity. The specific conductivity averaged 34.1 micromhos/cm from all dates and all depths. The chloride ion concentration was also among the lowest of the lakes involved in the LLMP, with an average of 2.4 parts per million. The low values of both these parameters indicate that Silver Lake is receiving little input of road salt, and/or raw sewage.

Phytoplankton

The density of phytoplankton on July 14 was low at both sites, with only 479 cells/milliliter at Site 2 and 585 cells/milliliter at Site 5. At this time, both sites were dominated by Diatoms (*Rhizosolenia*, and small pennate forms). Also of numerical importance during this time were species of green flagellates. At site 2, other groups of numerical importance included: Cryptomonads (*Chroomonas*), Chrysophytes (*Kephyrion*), and Cyanophytes (blue-green bacteria; *Merismopedia*). The presence of blue-green bacteria is often regarded as a sign of eutrophic tendencies, however the densities of *Merismopedia* were low, and may be related more to high surface water temperatures than to eutrophy.

Zooplankton

Herbivorous zooplankton densities on July 14 were low to moderate (3-10 organisms per liter). Zooplankton density was slightly higher at site 5 than elsewhere. Dominant groups included calanoid copepods and *Daphnia*. The low number of herbivorous crustacean zooplankton is related to the low algal density, because the productivity of zooplankton is dependant on algal production. Large numbers of herbivorous rotifers were noted at site 2. These organisms may be largely responsible for the low density of phytoplankton by grazing on them.

REFERENCES

Baker, A. L. 1973. Microstratification of phytoplankton in selected Minnesota lakes. Ph. D. thesis, University of Minnesota.

Brooks, J. L. and E. S. Deevey, Jr. 1963. New England. In: D. G. Frey (ed.), Limnology in North America. University of Wisconsin Press, Madison.

Carlson, R. E. 1977. A trophic state index for lakes. Limnol. Oceanogr. 22:361-379.

Davis, R. B., J. H. Bailey, M. Scott, G. Hunt and S. A. Norton. 1978. Descriptive and comparative studies of Maine lakes. Technical bulletin 88. Life Sciences and Agr. Exp. Station, University of Maine.

Edmondson, W. T. 1937. Food conditions in some New Hampshire lakes. In: Biological survey of the Androscoggin, Saco and coastal watersheds. (Report of E. E. Hoover.) New Hampshire Fish and Game Commission, Concord, New Hampshire.

Environmental Protection Agency. 1979. A manual of methods for chemical analysis of water and wastes. Office of Technology Transfer, Cincinnati. PA-600/4-79-020.

Gallup, D. N. 1969. Zooplankton distributions and zooplankton-phytoplankton relationships in a mesotrophic lake. Ph.D. Thesis, University of New Hampshire.

Forsberg, C. and S.-O. Ryding. 1980. Eutrophication parameters and trophic state indices in 30 Swedish waste-receiving lakes. Arch. Hydrobiol. 89:189-207.

Haney, J. F. and D. J. Hall. 1973. Sugar-coated Daphnia: a preservation technique for Cladocera. Limnol. Oceanogr. 18:331-333.

Hoover, E. E. 1936. Preliminary biological survey of some New Hampshire Lakes. Survey report no. 1. New Hampshire Fish and Game Department, Concord, New Hampshire.

Hoover, E. E. 1937. Biological survey of the Androscoggin, Saco and coastal watersheds. Survey report no. 2. New Hampshire Fish and Game Department, Concord, New Hampshire.

Hoover, E. E. 1938. Biological survey of the Merrimack Watershed. Survey report no. 3. New Hampshire Fish and Game Department, Concord, New Hampsire.

Hutchinson, G. E. 1967. A treatise on limnology, vol. 2. John Wiley and Sons, New York.

Hutchinson, G. E. 1973. Eutrophication. American Scientist 61:269-279.

Likens, G. E. 1975. Primary productivity of inland aquatic ecosystems. In: H. Lieth and R. H. Whittaker (eds.), Primary productivity of the biosphere. Springer-Verlag, New York.

Lind, O. T. 1979. Handbook of common methods in limnology. C. V. Mosby, St. Louis.

Lorenzen, M. W. 1980. Use of chlorophyll-Secchi disk relationships. Limnol. Oceanogr. 25:371-372.

Newell, A. E. 1970. Biological survey of the lakes and ponds in Cheshire, Hillsborough and Rockingham Counties. Survey report no. 8c. New Hampshire Fish and Game Department, Concord, New Hampshire.

Newell, A. E. 1972. Biological survey of the lakes and ponds in Coos, Grafton and Carroll Counties. Survey report no. 8a. New Hampshire Fish and Game Department, Concord, New Hampshire.

Newell, A. E. 1977. Biological survey of the lakes and ponds in Sullivan, Merrimack, Belknap and Strafford Counties. Survey report no. 8b. New Hampshire Fish and Game Department, Concord, New Hampshire.

New Hampshire Water Supply and Pollution Control Commission 1981. Classification and priority listing of New Hampshire Lakes. Staff report no. 121. Concord, New Hampshire.

Utermohl, H. 1958. Improvements in the quantitative methods of phytoplankton study. Mitt. int. Ver. Limnol. 9:1-25.

Warfel, H. E. 1939. Biological survey of the Connecticut Watershed. Survey report no. 4. New Hampshire Fish and Game Department, Concord, New Hampshire.

APPENDIX A

LLMP 1983 -- Lay Monitor Data: Silver   Jan-25-84   23:43.26

Date	Lake	Site	SDD	Chl
Jul-28-83	Silver	1	6.50	.76
Aug-02-83	Silver	1	7.30	.62
Aug-09-83	Silver	1	6.50	.52
Aug-19-83	Silver	1	6.70	.62
Aug-23-83	Silver	1	6.30	.95
Aug-30-83	Silver	1	6.70	1.09
Sep-07-83	Silver	1	7.30	.29
Sep-21-83	Silver	1	8.20	.62
Oct-05-83	Silver	1	8.90	.52
Oct-19-83	Silver	1	7.80	1.05
Jul-28-83	Silver	2	7.20	1.00
Aug-02-83	Silver	2	7.00	.57
Aug-09-83	Silver	2	7.50	.48
Aug-19-83	Silver	2	7.00	.67
Aug-23-83	Silver	2	7.00	1.09
Aug-30-83	Silver	2	6.50	1.00

Sep-07-83	Silver	2	7.50	.33
Sep-21-83	Silver	2	8.00	.38
Oct-05-83	Silver	2	8.80	.48
Oct-19-83	Silver	2	7.50	1.43
Jul-28-83	Silver	3	7.20	1.00
Aug-02-83	Silver	3	8.20	.90
Aug-09-83	Silver	3	7.10	.57
Aug-18-83	Silver	3	6.20	.71
Aug-22-83	Silver	3	7.10	.86
Aug-30-83	Silver	3	7.50	1.19
Sep-07-83	Silver	3	7.70	.33
Sep-21-83	Silver	3	7.70	.29
Oct-05-83	Silver	3	8.50	.62
Oct-19-83	Silver	3	7.70	1.00
Jul-28-83	Silver	4	---	1.00
Aug-02-83	Silver	4	5.50	.71
Aug-09-83	Silver	4	5.60	.86
Aug-18-83	Silver	4	---	.62
Aug-22-83	Silver	4	---	.71
Aug-30-83	Silver	4	---	.95
Sep-07-83	Silver	4	---	.29
Sep-21-83	Silver	4	---	.43
Oct-05-83	Silver	4	---	.81
Oct-19-83	Silver	4	---	.62

Jul-28-83	Silver	5	6.50	1.05
Aug-02-83	Silver	5	6.90	.76
Aug-09-83	Silver	5	6.00	.62
Aug-18-83	Silver	5	5.90	.90
Aug-22-83	Silver	5	6.20	.90
Aug-30-83	Silver	5	6.00	.90
Sep-07-83	Silver	5	6.30	.57
Sep-21-83	Silver	5	7.40	.36
Oct-05-83	Silver	5	8.30	1.09
Oct-19-83	Silver	5	7.10	.71

>>> END OF LIST <<<

APPENDIX B

CLARIFICATION OF SOME TERMS AND CONCEPTS

Thermal Stratification

Thermal stratification as a seasonal phenomenon is of prime importance in the lives of aquatic organisms. The formation of thermal layers affects many of the chemical and physical factors of their environment.

New Hampshire lakes are generally _dimictic_, with mixing of the water column occurring in the spring and fall. During periods of mixing, sometimes called _overturn_, the entire water column tends to circulate (_holomixis_). That is, the bottom-most waters are refreshed with water recently in contact with the atmosphere. The surface waters are enriched with water recently in contact with the bottom sediments. Some lakes, especially those with a high salt content toward the bottom of the basin, may be _meromictic_ and fail to mix (_overturn_) to the bottom.

During the spring, the entire water column circulates freely, resuspending and redissolving material from the bottom sediments. As the sun's intensity increases, the surface waters are heated so that they become buoyant and tend to float, creating a mixing-barrier with cooler water beneath. Eventually three layers are formed, called the upper-lake (epilimnion), middle-lake (metalimnion), and lower-lake (hypolimnion) (Fig. B-1). Characteristically, the epilimnion and hypolimnion are uniform in temperature, even though the upper lake is warm and the lower lake is usually very cold. In contrast, the temperature gradually or suddenly becomes cooler in the metalimnion (sometimes called the thermocline, or temperature gradient). The gradation in temperature corresponds to a gradient in other important characteristics of water, such as viscosity and specific gravity, that explain the presence of a mixing barrier between the epilimnion and the hypolimnion.

Depth of the metalimnion through the summer is variable, and is regulated to a large extent by the length of the wind-fetch on the lake (the length of lake aligned with the predominant axis of wind-storms). In the autumn, the sun's intensity decreases, the water in the epilimnion cools, and the mixing barrier weakens. Eventually the metalimnion disintegrates and the fall overturn occurs.

Ice and snow insulate the lakewater during winter, and the liquid lakewater cools to nearly freezing just under the ice layer, while it remains relatively warm further down in the water column (abcut 10 degrees Fahrenheit, or 4 degrees Celsius). Sometimes the overburden of snow after a heavy snowstorm in January or February may cause melt-holes to form in the ice, and the snow may turn to slush even while the air temperature is at its seasonal coldest (as low as 25 or 30 degrees below zero Fahrenheit)! This has caused some hysteria about 'radioactive things dropping from outer space' or 'radioactive substances dropping from jet planes' -- even though it is only the weight of snow! Scme reverse stratificaticn may cccur, with a layer of cclder water overlying the relatively warmer water below.

Two aspects of the seasonal thermal stratification cycle about which we are most ccncerned are vertical mixing (<u>overturn</u>) and the formation of stratified temperature layers during the summer.

Periods cf <u>overturn</u> are very important because of their effect of enriching the lakewater with material from the sediments. In <u>eutrophic</u> lakes, blocms of algae generally follow these periods in response to high concentrations of chemicals such as phosphorus, nitrogen, silica, and other essential <u>nutrients</u> -- those required for the growth of <u>microscopic algae</u>.

Effects of stratification will vary depending upon the depth of the lake or cove. In shallow areas, the epilimnion may extend to the bottom. If this is the case, the lakewater will constantly pick up material from the bottom usually resulting in a decrease in water transparency and an increase in algal growth.

One of the major consequences of a stratified lake system is reduced transportation of material between the bottom and surface. The effects of having a "barrier" within the water column are many but the most important include transport of nutrients from the epilimnion to the hypolimnion by sedimentation (enriching the hypolimnion at the expense of the epilimnion), and oxygen depletion in the hypolimnion.

Loss of nutrients from the epilimnion is due primarily to the sedimentation of plankton organisms such as algae and bacteria. The depletion of nutrients from the epilimnion is important for restricting the growth of algae during the summer, because the primary productivity of most lakes occurs only in the epilimnion. As a result of fall overturn the surface waters may become mixed with nutrient-rich bottom waters, and fall pulses of phytoplankton (freely-drifting microscopic algae) may develop.

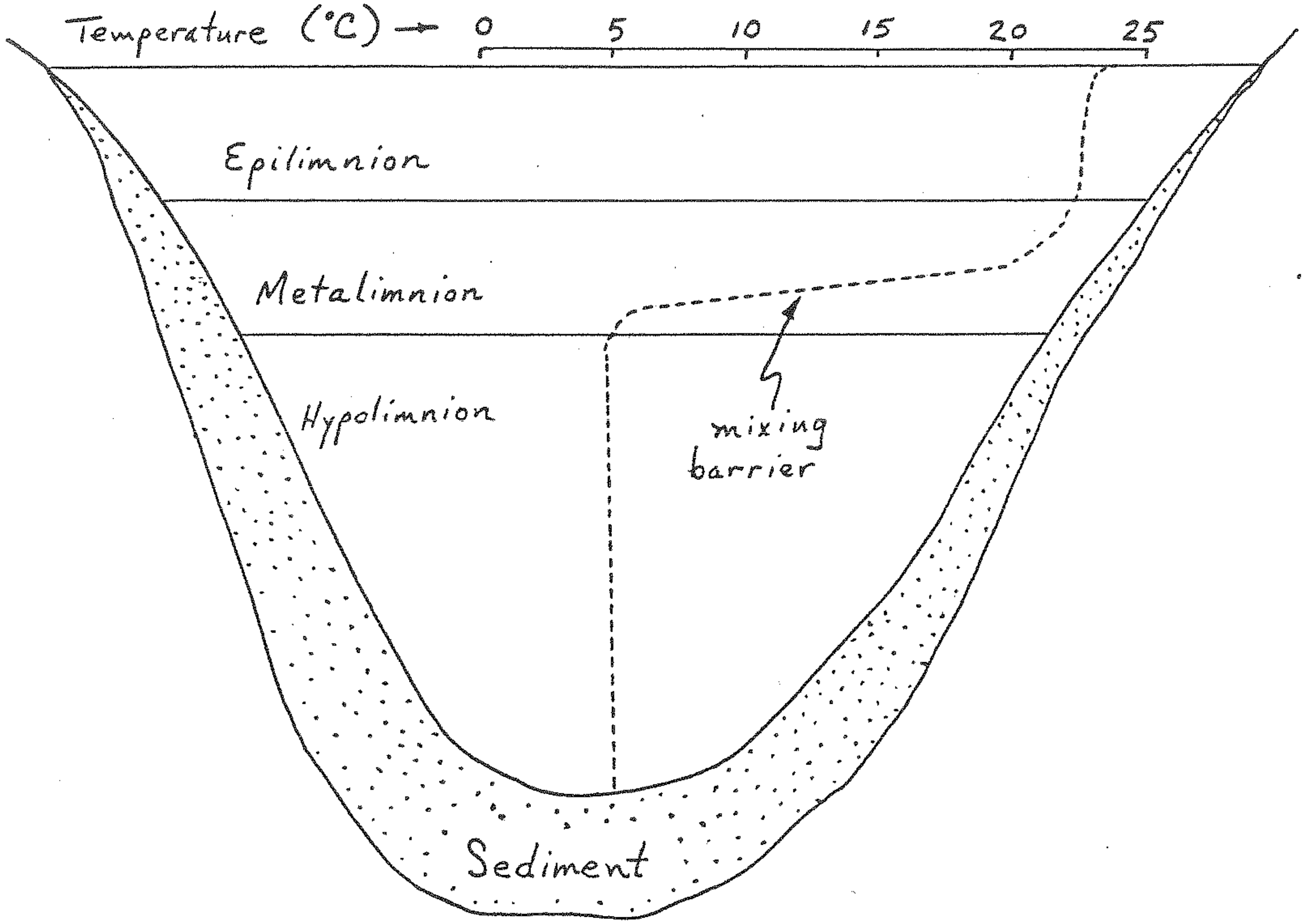

Figure B-1. Typical summer thermal stratification of a temperate lake. The 'metalimnion' provides a mixing barrier between the 'epilimnion' and the 'hypolimnion'. The dashed line represents the thermal profile, with cold water in the hypolimnion.

Oxygen Depletion

Oxygen depletion in the hypolimnion occurs for two reasons -- respiration by plants, bacteria and animals, and absence of mixing of the water column (combined with respiration). The resultant loss of oxygen plays an important role in regulating the depth regions within which aerobic (requiring oxygen) and anerobic (oxygen avoiding) organisms may thrive. The aerobic organisms include some bacteria, most algae, and all animals, and although they may have special adaptations to allow a tolerance to very low levels of dissolved oxygen, even for prolonged periods of time, they must occasionally obtain a supply of oxygen. The algae are the principal source of re-oxygenation by photosynthesis in the metalimnion, and the balance between oxygen production (by photosynthesis) and consumption (by respiration) is critical in determining the oxygen depletion in lakewater. The problem is minimal in surface waters, as the atmosphere overhead is a good source of oxygen.

Fisherman are acutely aware of the oxygen requirement of fish, and know that they can expect no laketrout fishing where oxygen has been depleted in the cool bottom waters of a lake. In fact, the laketrout, as well as related species of fish, are entirely eliminated from such lakes. Even though the surface waters are well oxygenated, the temperature is too high to support the salmonid-type fish.

Most people are unaware that important groups of micro-organisms thrive in the <u>anoxic</u> (lacking oxygen, similar to <u>anaerobic</u>) bottom waters of lakes. For the most part, these are the important groups of bacteria that regulate cycles of <u>nutrients</u> at or near the bottom of such lakes. The bacteria are involved in crucial processes that may determine the chemical quality of the lake -- including modification of all <u>nutrients</u> essential to growth of the <u>microscopic</u> <u>algae</u> -- such as carbon, phosphorus nitrogen, and sulphur, by <u>putrefaction</u> or break-down of dead organisms, and by <u>fermentation</u>. The <u>anaerobic</u> bacteria are also involved in processes such as nitrogen fixation that converts unavailable nitrogen to very-available ammonia, and in the formation of a large host of dissolved organic substances such as vitamins that promote the growth of <u>microscopic</u> <u>algae</u>. In general, the <u>anaerobic</u> bacteria can be viewed as the principal agents involved in promoting <u>recycling</u> of essential <u>nutrients</u> that otherwise would have been lost and locked up in the lake sediments.

<u>Water transparency</u>

Water <u>transparency</u>, as indicated by secchi disk depth, is influenced by many factors. Dissolved substances such as <u>humic</u> <u>acids</u> (tea-colored coloring matter from plant decay) will frequently lend a yellow or brown color to the water, thus decreasing its <u>transparency</u>. The <u>humic</u> <u>acids</u> are especially prevalent in waters running through bogs or coniferous forests.

Another factor affecting water transparency is the number of particles suspended in the water column. These particles are of two types: sediments and living organisms. Sediments are especially prevalent in areas where mixing occurs all the way to the bottom, as during overturn of holomictic lakes. Human activity such as boating or swimming can also resuspend sediments. Among living organisms, phytoplankton has the greatest effect on water transparency, due to its pigmentation and abundance. Chlorophyll a, the pigment common to all photosynthetic phytoplankton, is used as one measure of phytoplankton density.

Water transparency (measured as the Secchi Disk Depth), chlorophyll a and thermal stratification, along with other important physical, chemical and biological obsevations of study lakes, are the core of the lay monitoring program. Long- or short-term trends in these data can be used as indicators of changing trophic status of lakes.

Lake Trophic Status

Every classification scheme suffers from over-simplification! The very act of classifying requires the definition of classes within which study objects may be placed or pigeon-holed. Often the classes are defined by some arbitrary means, and the boundaries are subject to change depending upon the definition that is used. The fundamental problem with the process of classification is that once boundaries are set and classes are defined, we tend to think of the classes as somehow isolated from each other. Instead they may blend into each other at the boundaries. As you consider the classification scheme, please think of a continual gradient of individual lake types, through which any lake may pass. The passage may require a long period of time, given changes in the landscape or climate by natural causes, or a relatively short time given human-induced changes in use of the lake or its shoreline and watershed. One may hope that the following five categories of trophic status will help to simplify what we know about lakes, yet leave us with a sense of the probable evolution of lakes between classes of trophic status.

Three major categories of trophic status include oligotrophy, mesotrophy, eutrophy. Oligotrophic lakes characteristically have high transparency and low concentrations of chlorophyll a and phosphorus. Therefore, a large fraction of the visible portion of sunlight radiation, including from blue through red light, can penetrate to great depths in the lakes. Mesotrophic lakes are intermediate, and eutrophic lakes have relatively low transparency and high concentrations of chlorophyll a and phosphorus. Due to the high chlorophyll concentration, restrictions are placed on the transmission of sunlight into eutrophic lakes -- especially on blue and red light that are absorbed in the upper waters of the lakes by microscopic algae. Generally green light penetrates furthest into such lakes, and although it can be used in photosynthesis, it is less efficient than red or blue light. Thus photosynthesis is more restricted to upper layers in eutrophic lakes than in less-productive lakes. Two additional major categories of lakes are dystrophy and mixotrophy. Lakes in these two categories have a high concentration of humic acids, and thus are heavily stained. Light penetration is severely restricted by the tea-colored stain, and only the red portion of sunlight is transmitted beneath the surface. Therefore, microscopic algae can grow only near the surface, and even then are light-limited (little or no blue light is transmitted to them). If such a lake has a low concentration of microscopic algae -- indicated both by algal counts (with a microscope) and by a low chlorophyll a concentration, the lake is called dystrophic. It is probable that the lake has a low input (loading) of nutrients, so that the microscopic algae are limited both by low light level and by low nutrient levels. However, if the lake receives a large loading of fertilizer, supplying an abundance of phosphorus, nitrogen and other essential nutrients, the microscopic algae may form a relatively concentrated community, and thus the chlorophyll a concentration rises. Such a lake is called mixotrophic -- a 'mixture' of organisms produced within the lake with imported organic material (mainly humic substances) from bogs or other sources outside the lake basin.

Plankton

Microscopic organisms found throughout the water column of lakes belong to the plankton, or plankton community. Members of the community are especially adapted for life in the open water where they must be able to resist gravity to stay in suspension, and to capture energy for survival. Important members of the plankton community are all microscopic, and belong to several different groups of bacteria, algae, fungi, and animals. In some cases the organisms spend their entire life in the open water, while in other cases only a fraction of their life (usually early stages, as in some insects). Students of biology are often attracted to the plankton community because of the immense diversity of organisms and processes that occur within it, because of its relative importance to a body of water, and especially because much about life of larger organisms can be learned from these special plankton organisms.

Interactions between the plankton community and lakewater determine to a very large extent the trophic status of lakes. In addition, a firm foundation is laid for the long-term management of lakes when the characteristics of the plankton community and the lakewater are determined.

Seasonal changes in both the planktors (members of the plankton community) and in the water chemistry require that several observations be made each year in a lake. Annual changes are generally slower, and can be discerned only during the course of long-term monitoring of principal parameters of plankton and water chemistry.

It is beyond the scope of this section of the report to describe all of the important changes that occur in the plankton as a lake passes through various trophic stages (oligotrophy, mesotrophy, etc.). But foremost among these is the change in concentration of plankton organisms -- especially the microscopic algae. This change is usually regulated by chemical loading into lakes, but is also regulated by seasonal changes in weather, and by several biological processes that occur in lakes -- such as grazing by microscopic crustaceans (water fleas and their allies). A good monitoring program includes not only an analysis of numbers of planktors, but also of types. Predictions of trophic evolution in lakes may be discerned more quickly by observing such changes in the plankton.

APPENDIX C

GLOSSARY

Aerobe	Organisms requiring oxygen for life. All animals, most algae and some bacteria require oxygen for respiration.
Algae	See phytoplankton.
Alkalinity	Total concentration of bicarbonate and hydroxide ions (in most lakes).
Anaerobe	Organisms not requiring oxygen for life. Some algae and many bacteria are able to respire or ferment without using oxygen.
Anoxic	Without oxygen. The hypolimnion of a lake may become anoxic if there are many organisms using oxygen for respiration and there is little replenishment from the atmosphere.
Benthic	Referring to the bottom sediments.
Bacterioplankton	Bacteria adapted to the "open water" or "planktonic" zone of lakes, adapted for many

specialized habitats and include groups that can use the sun's energy (phytoplankton), some that can use the energy locked in sulfur or iron, and others that gain energy by decomposing dead material.

Bicarbonate — The most important ion (chemical) involved in the buffering system of New Hampshire lakes.

Buffering — The capacity of lakewater to absorb acid with a minimal change in the pH. In New Hampshire the main chemical responsible for buffering is the bicarbonate ion. (See pH.)

Chloride — One of the components of salts dissolved in lakewater. Generally the most abundant ion in New Hampshire lakewater, it may be used as an indicator of raw sewage or of road salt.

Chlorophyll a — The main green pigment in plants. The concentration of chlorophyll a in lakewater is often used as an indicator of algal abundance.

Circulation — The period during spring and fall when the combination of low water temperature and wind cause the water column to mix freely over its entire depth.

Density — The weight per volume of a substance. The more dense an object, the heavier it feels.

Low-density liquids will float on higher-density liquids.

Dimictic — The thermal pattern of lakes where the lake circulates, or mixes, twice a year. Other patterns such as polymictic (many periods of circulation per year) are uncommon in New Hampshire. (See also meromictic and holomictic).

Dystrophy — The lake trophic state in which the lakewater is highly stained with humic acids (reddish brown or yellow stain) and has low productivity. Chlorophyll a concentration may be low or high.

Epilimnion — The uppermost layer of water during periods of thermal stratification. (See lake diagram).

Holomixis — The condition where the entire lake is free to circulate during periods of overturn. (See meromixis.)

Eutrophy — The lake trophic state in which algal production is high. Associated with eutrophy is low Secchi disk depth, high chlorophyll a, and high total phosphorus. From an esthetic viewpoint these lakes are "bad" because water clarity is low, aquatic plants are often found in abundance, and cold-water fish such as trout and salmon are usually not present. A good aspect of eutrophic lakes is their high productivity in terms of warm-water fish such as bass, pickerel, and perch.

Free CO2 — Carbon dioxide that is not combined chemically with lakewater or any other substances. It is produced by respiration, and is used by plants and bacteria for photosynthesis.

Humic acids — Dissolved organic compounds released from decomposition of plant leaves and stems. Humic acids are red, brown, or yellow in color and are present in nearly all lakes in New Hampshire. Humic acids are comsumed only by fungi, and thus are relatively resistant to biological decomposition.

Hydrogen ion — The ion which is measured to indicate acidity. (See pH).

Hypolimnion — The deepest layer of lakewater during periods of thermal stratifiction. (See lake diagram)

Lake — Any "inland" body of relatively "standing" water. Includes many synonyms such as ponds, tarns, lochs, billabongs, bogs, marshes, etc.

Lake morphology — The shape and size of a lake and its basin.

Meromixis — The condition where the entire lake fails to circulate to its deepest point; caused by a high concentration of salt in the deeper waters, and by peculiar landscapes (small deep lakes surrounded by hills and/or forests.

Mesotrophy — The lake trophic state intermediate between oligotrophy and eutrophy. Algal production is moderate, and chlorophyll a, secchi disk depth, and total phosphorus are also moderate. These lakes are esthetically 'fair' but not as good as oligotrophic lakes.

Metalimnion — The 'middle' layer of the lake during periods of summer thermal stratification. Usually defined as the region where the water temperature changes at least one degree Celsius per meter depth. Also called the thermocline.

Mixis — Periods of lakewater mixing or circulation.

Mixotrophy — The lake condition where the water is highly stained with humic acids, but algal production and chlorophyll a values are also high.

Oligotrophy — The lake trophic state where algal production is low, Secchi disk depth is deep, and chlorophyll a and total phosphorus are low. Esthetically these lakes are the "best" because they are clear and have a minimum of algae and aquatic plants. Deep oligotrophic lakes can usually support cold-water fish such as lake trout and land-locked salmon.

Overturn See circulation or mixis.

pH A measure of the hydrogen ion concentration of a liquid. For every decrease of 1 pH unit, the hydrogen ion concentration increases 10 times.

Photosynthesis The process by which plants convert carbon dioxide into glucose (sugar) using sunlight as the energy source. Glucose is an energy source for growth, reproduction, and maintenance.

Phytoplankton Microscopic algae which are suspended in the 'open water' zone of lakes and ponds. A major source of food for zooplankton. Common examples include: diatoms, euglenoids, dinoflagellates, and many others. Usually included are the blue-green bacteria.

Parts per million Also known as PPM. This is a method of expressing the amount of one substance (solute) dissolved in another (solvent). For example, a solution with 10 PPM of oxygen has 10 pounds of oxygen for every 999,990 pounds (500 tons) of water.

Plankton Community of microorganisms that live suspended in the water column, not attached to the bottom sediments or aquatic plants.

Saturated — When a solute (such as water) has dissclved all of a substance that it can. For example, if you add table salt to water, a point is reached where any additional salt fails to dissolve. The water is then said tc be saturated with table salt. In lakewater, gaseous oxygen can dissclve, but eventually the water becomes saturated with oxygen.

Specific conductivity — A measure of the amount of salt present in lakewater. As the salt concentration increases, so does the specific conductivity (electrical conductivity).

Stratum — A layer or a "blanket". Can be used to refer to one of the major layers of lakewater such as the epilimnion, or to any layers of organisms or chemicals that may be present in a lake.

Thermal Stratification — The process by which layers are built up in the lake due to heating by the sun and partial mixing by wind. (See Appendix B.)

Thermocline — Region of temperature change. (See metalimnion.)

Total Phosphorus — A measure of the concentration of phosphorus in lakewater. Includes both free forms (dissolved), and chemically combined form(as in living tissue, or in dead but suspended organisms).

Trophic status A classification system placing lakes into similar groups according to their amount of algal production. (See Oligotrophy, Mesotrophy, Eutrophy, Mixotrophy, and Dystrophy for definitions of the major categories, and Appendix B)

Z A symbol used by limnologists as an abbreviation for <u>depth</u>.

Zooplankton Microscopic animals in the planktonic community. Some are called 'water fleas', but most are known by their scientific names. Scientific names include: <u>Daphnia</u>, <u>Cyclops</u>, <u>Bosmina</u>, and <u>Kellicottia</u>.